

ANAEROBIC DIGESTION AND WETLAND TREATMENT CASE STUDY:  
COMPARING TWO MANURE ODOR CONTROL SYSTEMS FOR DAIRY FARMS

by

Peter E. Wright  
Senior Extension Associate  
Department of Agricultural and Biological Engineering  
Cornell Cooperative Extension  
Ithaca, NY, USA

Stephen P. Perschke  
Area Engineer  
UDSA Natural Resources Conservation Service  
Batavia, NY, USA

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**Summary:**

A comparison of two existing odor control treatments on dairy farms in NY shows the costs and benefits of each system. On one dairy farm an anaerobic digester is used to stabilize the manure and collect methane for the production of electricity. The effluent is then separated. The solids are sold, and the liquid effluent is then land applied. The other dairy farm uses a wetland treatment system. This farm uses flushing to carry the manure to shallow ponds for solid settling. The solids are recovered for off site sale. The liquid effluent is treated in a facultative lagoon. The effluent from the lagoon is recycled for use as the liquid for flushing the barn and land applied. These systems have different costs, nutrient utilization and management concerns. Both of these systems achieve significant odor control and are feasible alternatives for dairy farms.

**Keywords:**

Manure treatment, Odor control, Dairy farms, Economics, Nutrients

## **Introduction**

Dairy farms are coming under increasing pressure to control the odors from their operations. Often nutrient management plans designed to protect water quality prescribe manure storage. Stored manure can produce objectionable odors, creating a conflict with neighbors. By comparing two feasible alternatives to manure handling that achieve odor control, agricultural engineers and producers will be better able to choose an effective and economically viable system for farms. These systems improve neighbor relations, reduce the impact on the environment, and will help provide for sustainable development of the dairy industry.

## **Objective**

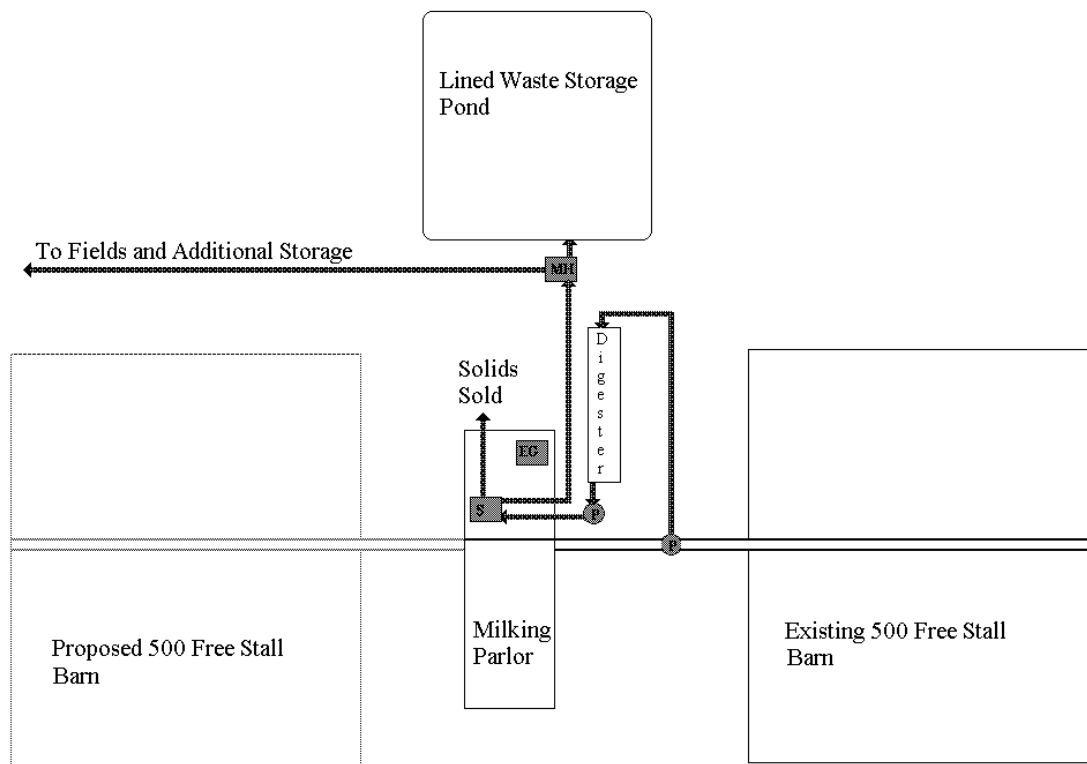
The objectives of this paper are to show the material flow, nutrient content, and costs of two different manure handling systems. The advantages and disadvantages of each system are described so that managers can decide if either system will meet their needs as a manure handling system.

## **Farm A**

This dairy farm is a 500 cow operation located in a rural community in south central NY. The farm is owned and managed by one family. They are in the process of completing their business plan goal of milking 1,000 cows. However, water quality and odor concerns from the community that their land surrounds has led them to choose a manure handling system that will both allow them to utilize the nutrients in the manure and allow them to control odors produced by the manure.

Figure 1 shows the layout of Farm A's buildings and manure handling system. There is a planned 500 cow freestall to the West of the existing milking center. The milking center and bunk silo are sized to meet the capacity of a 1,000 cow herd. Their original plan was to expand rapidly to a 1,000 cow herd.

**Figure 1. Farm A layout of manure handling system.**



They were unprepared to handle the manure produced at the facility as they started operating in the summer of 1993. Manure and wash water were stored in an underground reception pit at the back of the holding area. This pit could store manure and waste water from the milking parlor for about two weeks. This was a long enough time for the manure to partially decompose producing a putrid odor. Due to equipment problems and limited land to spread the manure, 2 week old manure was spread daily the first summer. The opposition that they faced from the community as the 500 cow barn began operation was tremendous. The people in the village objected to this new system, but under NY's right to farm law they could not prevent the farm from operating.

Water quality issues could stop the farm from operating. The majority of the farm's 1200 acres are on well drained valley land. The farm lies on the primary aquifer for the village, the school, as well as many private wells used for drinking water. The nearby creek has been identified as having water quality problems due to high nutrient and organic loading and is on NYSDEC's priority water problem list.

To address these water quality issues while using the manure as the main nutrient source for the farm, the best solution would be to store the manure and apply it only when the crops were growing or immediately before the crops were to be planted. This strategy would result in all the corn land being spread heavily with manure in the spring and the hay crops topdressed with manure after each cutting throughout the summer. The odor from these operations would create a major public relations problem for the farm.

Anaerobic digestion could provide a way to reduce the odor in the manure, reduce the solids content of the manure to improve irrigation operation, and perhaps recover some costs from energy production. The larger the farm the greater the economic feasibility of anaerobic digestion. Methane production has efficiencies of scale that turn positive at around 500 cow

farm sizes. Anaerobically digested manure has a significantly limited odor. Most easily digested organic matter will be broken down in the anaerobic digestion process. The gas production is controlled and burned so no odors escape from the digestion process. The resulting effluent is mostly inert organics and does not develop the objectionable odors that raw manure storage produces.

As the manure is anaerobically digested some of the solids are converted to methane gas, carbon dioxide gas and water. About 4% of the solids are converted reducing the solid content and raising the moisture content of the effluent about 4%. This change in addition to some breakdown of the fibers in the manure, makes the resulting effluent much easier to pump. Solid separation systems also seem to work better on digested effluent than on the raw manure.

Dairy manure from 500 cows is estimated to produce about 42,000 cubic feet of biogas per day. Using a 70 kW engine and generator this could produce about 1390 kW/d of electricity and allow significant heat recovery from the engine. It may be difficult to sell the electricity and to use all the heat produced. There have been a number of anaerobic digesters installed on farms. These systems have a mixed record of success. They are more likely to get the management attention they need to work well where needed as an odor control system.

### **Anaerobic Digestion Description**

Manure from the 305 foot by 360 foot free stall barn is automatically scraped into a cross alley with step dams to facilitate gravity manure flow. Ten cubic yards of kiln dried shavings are used for bedding each week. The barn is insulated below the rafters with 1.5 inches of foil faced insulation. This was done to minimize the time that manure would freeze, both to keep the alley scrapers running during the winter as well as to limit the heating requirements for the manure. The 20 hp submersible manure pump is used to pump manure into the digester once a day. This pump cost \$9,000 and is used 1.5 hours a day.

The digester is a plug flow concrete tank 136 feet long by 30 feet wide by 14 feet deep. The engineering design was valued at \$20,000. It was sized to provide a hydraulic retention time of 20 days when the herd gets to 1000 cows. It cost \$160,000 to build which includes the floating insulation, the gas containing cover, and two hot water heating circuits. Both circuits can use the heat off the engine or heat from a separate boiler if the engine is not working. One circuit in the front end of the digester is used to heat the incoming manure while the other circuit runs the length of the digester and is on a different thermostat to maintain the temperature of the manure at about 100 degrees Fahrenheit.

The gas is run to a 130 kW 3306 Caterpillar engine. The engine is a diesel block with a natural gas head that can be easily converted to run on biogas. The engine runs an induction generator to produce the electricity that replaces 9 cents per kW electricity used by the farm. The extra is sold back to the utility at 2 cents per kW, which is the wholesale price. The farm averaged \$3,000 per month of electricity on all their sites. They expect to reduce this to \$1,000 per month with the cogeneration system. This generator will not work if the electric utility fails since the induction generator needs an input from the utility to produce electricity. For emergencies a stand by generator will need to be installed.

The engine generator and switching equipment was purchased used for \$15,000. Additional costs were \$6,000 to rebuild the engine, \$2,000 to rebuild the generator, \$9,000 for other

plumbing, electric, and mechanical systems, \$8,000 to run 265 feet of parallel 3 phase cable to the utility hook-up, \$18,000 for an electrical engineer consultant, and \$5,000 to obtain the utility permit. This system is sized for an ultimate herd size of 1,000 cows. Five hundred cows will produce about 55 kW; 1,000 cows will produce about 110 kW. The maintenance cost of the digester and cogeneration system is expected to be about 1.5 cents per kW hour or about \$15,000 per year. This includes oil changes, parts, replacing the digester cover and grit removal. The normal maintenance may average one half an hour per day.

The effluent leaving the digester is 6.7% solids. It is pumped to a screw press separator with a 7.5 Hp pump. This pump cost \$1,800 and has a \$1,200 variable speed drive. The screw press separator will produce about 0.6 cubic foot of 30% solid recycled manure every half minute of operation. That rate will handle about two cows daily manure production per minute. This rate may change depending on the size of the solids, the moisture content of the manure slurry, and the internal wear on the auger vanes. The separator does seem to work better with digested manure than with raw manure. The remaining slurry is reduced in volume by about 15% allowing more storage time for existing storage facilities. The slurry has 4.5% solids remaining in it so it pumps much easier than unseparated raw manure.

The separation equipment costs about \$25,000 for the machine, and is housed in a \$25,000 existing building. The separator uses 4 kW to turn the auger, and 0.15 kW to run a vibrator to keep the manure entering smoothly. There is a definite ammonia odor during this process. Ammonia is lighter than air so this will not be an off site odor problem.

The solids are sold to a bulk soil amendment processor for \$8 per cubic yard. The liquids flow by gravity to a 2,400,000 gallon lined waste storage pond to be stored or pumped to an existing 2,200,000 gallon waste storage pond convenient to some of the crop fields. The lined pit cost \$18,000 for the excavation, fence, pipe, and outlet structure, and \$42,000 for the liner. The liner was needed because of the gravel soils at the farmstead. Five miles of 6 inch diameter plastic pipe will be buried to move the effluent to the remote waste storage pond and to the fields. This pipe cost \$2.50 per foot installed with valves and risers for access.

An irrigation pump and reel with a hard hose and big gun applicator will be purchased to apply the manure to growing crops. The digestion process should reduce the weed seeds and pathogens present in the manure. Effects of unpalatableness from manure spread on growing crops should also be reduced. The anaerobic digestion to remove odors, and lowering the solid content with anaerobic digestion, solid removal and dilution should make the irrigation equipment run smoothly. Irrigation costs have been estimated from other operations at thirty-four dollars per hour. They were calculated from a 100 Hp chopper pump, 1.23 operators, 1 mile of portable pipe, and a tractor run 23 % of the time to set up the traveling gun reel. The costs of irrigation will not be included in the process evaluation.

Samples of manure were taken at the end of each process in this system. The manure before and after anaerobic digestion was sampled, as well as both flows from the separator. The manure storage pond was sampled prior at the surface after winter storage. There could be significant variation in these samples especially the one from the waste storage pond. Dilution by precipitation, milking center wash water, as well as settling may have distorted the nutrient contents. Table 1 shows the percentages from each sample.

**Table 1. Manure characteristics and estimated amounts per cow from Farm A Anaerobic Digestion System.**

|                          | %M | %N   | %P   | %K   | Lb. |
|--------------------------|----|------|------|------|-----|
| As produced per day      | 90 | 0.44 | 0.09 | 0.29 | 152 |
| After digestion per day  | 93 | 0.45 | 0.07 | 0.26 | 146 |
| Separated liquid per day | 95 | 0.43 | 0.06 | 0.28 | 126 |
| Separated solids per day | 77 | 0.51 | 0.11 | 0.26 | 21  |
| From storage per day     | 98 | 0.27 | 0.02 | 0.16 | 165 |
| Nutrients available      |    |      |      |      |     |
| Lb. per year             |    | 163  | 12   | 97   |     |

In table 1, the mass for the digester effluent was estimated based on the change in moisture content in the samples. The mass of solids was estimated using previously measured densities of the separated solids of 30 pounds per cubic foot. The mass of the separated liquid was determined by subtracting the mass of the separated solids. The mass of the stored liquid was estimated by adding in the average precipitation for 180 days.

Predicting the amounts and concentrations of the nutrients is difficult. Obtaining representative samples and estimating the losses from biological, chemical, and physical processes in the system can be difficult. The biological reactions are not monitored or controlled fully and there are some physical factors that are uncontrolled in the storage pond that can effect the nutrient concentrations.

### **Costs on Farm A**

The \$365,000 first year expense for this system is high, but there is more opportunity for potential returns. After converting to a present value over a 20 year life with 8% interest, the net per cow benefit is \$698.22. Sales of electricity are assumed to be \$24,000 per year. The sales of solids are assumed to be \$32,445 per year, and assuming the value of the nutrients at \$0.25 per pound; the nutrients remaining are worth \$34,060 per year. There are of course many factors not taken into account in this analysis. The nutrients were assumed to be needed when it may be that only nitrogen is needed on the farm. The electric value will depend on a number of pricing and production interactions. The sales of the solids hopefully will continue without competition from another farm that might be closer to the market providing the organic material at a lower cost.

Yearly expenses include \$15,000 per year for the maintenance of the digester, engine, and generator. This will include occasionally replacing the cover and removing the grit in the bottom of the digester. The engines and generator repairs and scheduled overhauls are also included in this yearly cost as is the one half hour of daily maintenance to check the system. The spreading costs of the manure were ignored as well as the offsite storage. The cost of the alley scrapers is also not included in the system. The pumps were estimated to have a 10 year useful life. Their replacement was included in the present value calculation. These costs are shown in table 2.

**Table 2. Costs for anaerobic digestion manure handling system for Farm A.**

| Present Value | Yearly Amount |
|---------------|---------------|
|---------------|---------------|

|                           |             |            |
|---------------------------|-------------|------------|
| First Year Expense        | (\$365,000) |            |
| Ten Year Expense          | (\$22,696)  |            |
| Operation and Maintenance | (\$151,786) | (\$15,460) |
| Nutrient Value Remaining  | \$334,406   | \$34,060   |
| Solids Sold               | \$318,550   | \$32,445   |
| Electricity Sold          | \$235,636   | \$24,000   |
| Net Income                | \$349,109   |            |
| Net Income per Cow        | \$698       | \$35       |

Without including the nutrient value the system has a present value of \$1 per cow over the 20 year life of the system. Some farms may not be able to obtain a benefit from the manure. Farms with fields that have high to excessive levels of phosphorus and potassium may even see these nutrients as a detriment. Appropriate nutrient management will be needed to utilize the nutrients to maximize crop uptake. The ability to irrigate the effluent on growing crops without excessive odors will increase the likelihood that the nutrients can be used.

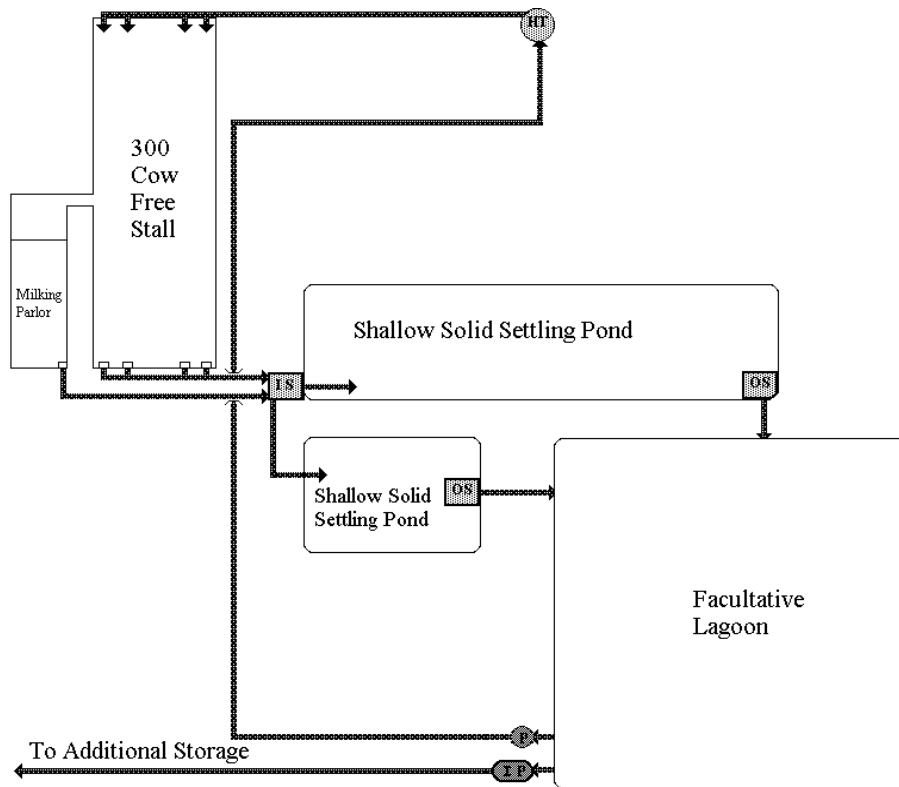
## **Farm B**

This dairy farm is presently a 170 cow operation located in a rural area of the south west part of NY State. The farm is owned and managed by one family. They rebuilt and expanded their farm in 1993 when a fire destroyed their tie stall barn. Their present facility can hold up to 300 cows. They may expand beyond that some time in the future. They chose a manure handling system that will both allow them to minimize labor and allow them to control odors produced by the manure. They hope that sales of the solids produced can help their cash flow.

Figure 2 shows the layout of Farm B's buildings and manure handling system. This farm site is on a fairly steep hillside. This facilitates the gravity flow of the manure system but added to the construction costs for extra earthmoving. The producer chose a new wetland treatment system for manure handling that seemed to work well with his idea of minimizing labor by using a flush system to remove the manure from the freestall barn.

The Bion system is a patented process that uses managed shallow ponds to separate the manure solids into aquatically stabilized solids. These solids are then harvested, dried, screened and sold as a soil amendment. The system recycles the biologically active liquid to move the manure through the ponds. The water from the facultative lagoon is used to supply the flush water for the system. Odors are much reduced when this system is operating correctly. The effluent from the facultative lagoon is relatively low in nutrients. Ammonium nitrogen is lost into the air from this system. Some nutrients are moved off the farm as solids. There may be significant settling of phosphorus in the bottom of the facultative lagoon.

**Figure 2. Farm B layout of manure handling system.**



### **Wetland System Description**

Manure from the four freestall alleys is flushed 3 times a day into the wetland system. Each flush consists of 10 thousand gallons of recycled water from the facultative lagoon. There is no noticeable odor in the barn as the flush system is operated. The Waterman flush valves are opened for 4 to 6 minutes per alley. The alleys are sloped at a one percent grade toward 6 inch wide grate covered drop inlets that lead to a 30 inch smooth plastic pipe that outlets next to the first shallow settling pond. This flow from the barn flush as well as flows from the milking center and silage juice from the bunk are controlled and routed to the two shallow settling ponds. The milking center water can only go to the smaller pond because the elevation of the larger pond is too high. The pipes, valves, and holding tank to deliver the flush water to the barns and return it to the wetland system cost \$32,089. This includes the four flush valves that each cost \$550.

The settling ponds are designed to slowly build up solids forcing new flows through the existing solids on the way to the outlet. The excavation for the ponds cost \$60,000 plus \$950 for the survey. The outlet structures allow up to two feet of solid build up while letting the liquids drain out. When the larger pond is full, the flows are directed to the smaller pond until the solids are drained and harvested. The smaller pond is then cleaned by adding water, agitating and pumping to the larger pond.

The removal of the manure solids is done every year from the larger pond. A back hoe with a 32 foot reach is used for 48 hours to place the material on the banks. The track mounted backhoe with an operator cost \$70 per hour. Bion provides the management and marketing of the "Bion



Soils". When the material is dry and sold a \$5 per cubic yard payment is given to the farmer. The average amount sold per year is 1200 cubic yards or about 0.5 cubic feet per cow per day.

The liquids from the shallow solid settling ponds outlet into the 25 foot deep facultative lagoon. There is evidence of biological activity since fairly continuous gas bubbles up in the lagoon. The liquids are stored in the facultative lagoon, pumped to an additional 1.5 million gallon waste storage pond, and then applied to the 440 acres of farmed land from both the satellite storage as well as from the facultative lagoon.

The lagoon holds 2 million gallons of waste water. An intake suspended two feet below the surface recycles the waste water through a 10 Hp self priming closed impeller, centrifugal pump, costing \$1,880, to a holding tank 27 feet higher in elevation than the barn. This 20,000 gallon holding tank provides the flush water to clean the barn. The pump can deliver 100 gallons a minute and runs 20 hours per day. The electric rate on this farm is 5.5 cents per kW from an electric co-op.

By using this recycled water, only the water from the milking center, silage leachate, and precipitation is added to the manure system. The farm's records show that the amount of waste water spread on the fields from the system for 1997 was about equal to the manure and wastewater added. One of the perceived draw backs to this system is the extra water handling from the surface area of the wetland. There are about twelve acres that would add precipitation and runoff to the site and about 3.5 acres of surface area for evaporation. There is the possibility that the biological reactions in the wetland area increase the evaporation to cancel out the extra precipitation. An unknown amount of water has overflowed from the facultative lagoon in extreme events.

An irrigation pump and reel with a hard hose and big gun applicator will be purchased to apply the manure to growing crops. There is a slight musty odor as the effluent is irrigated. The Bion system should reduce the weed seeds, and some of the pathogens present in the manure. Effects of unpalatableness from manure spread on growing crops should also be reduced. The low solid content of the effluent from the facultative lagoon should make the irrigation equipment run smoothly. Irrigation costs have been estimated from other operations at thirty-four dollars per hour. They were calculated from a 100 Hp chopper pump, 1.23 operators, 1 mile of portable pipe, and a tractor run 23 % of the time to set up the traveling gun reel.

Samples of the solid leaving the farm and the liquid effluent being applied to the fields were taken in this system. There is a significant variation in these samples from ones taken in 1997. There are differences due to the weather and the uncontrolled nature of the biological processes that will make the nutrient concentrations and the volume of waste water vary considerably. Dilution by precipitation, milking center wash water, and silage leachate as well as settling may have distorted the nutrient contents. Table 3 shows the percentages from each sample from the spring of 1998.

**Table 3. Manure characteristics and estimated amounts per cow from Farm B Wetland treatment system.**

|                  | %M | %N   | %P   | %K   | Lb. |
|------------------|----|------|------|------|-----|
| As produced      | 90 | 0.40 | 0.09 | 0.30 | 152 |
| Separated liquid | 99 | 0.08 | 0.01 | 0.07 | 135 |

|                     |    |      |      |      |      |
|---------------------|----|------|------|------|------|
| Separated solids    | 83 | 0.37 | 0.10 | 0.07 | 17.5 |
| Nutrients available |    |      |      |      |      |
| Lb. per year        |    | 39   | 5    | 35   |      |

In table 3, the mass of solids was estimated using previously measured densities of the separated solids of 35 pounds per cubic foot. The mass of the separated liquid was determined by subtracting the mass of the separated solids. This mass was compared to the amount reported spread in 1997 and was only 10% lower. The farmer reported irrigating 148 pounds of liquid per cow per day in 1997.

Predicting the amounts and concentrations of the nutrients in this system is even more difficult. Obtaining representative samples and estimating the losses from biological, chemical, and physical processes in this relatively uncontrolled system can be difficult. The biological reactions are not monitored or controlled and the temperature, precipitation, and evaporation are uncontrolled in the ponds. There can be a large effect on the nutrient concentrations.

Bion Technologies, Inc. is designing and installing these systems throughout the US. The capital costs for the installation and a management fee would be paid to this company and the profits from the sale of the solids would be split between the company and the farmer.

### **Wetland Costs**

The \$94,919 first year expense for this system is a moderate investment for a manure handling system. There is some opportunity for potential returns, but the revenues from the sale of the solids have to be split with the managing partner. After converting to a present value over a 20 year life with 8% interest, the net per cow cost of this system is (\$390.27). The sales of solids are assumed to be \$6,000 per year, and assuming the value of the nutrients at \$0.25 per pound the nutrients remaining are worth \$3,354 per year. There are of course many factors not taken into account in this analysis. The nutrients were assumed to be needed when it may be that only nitrogen is needed on the farm. The sales of the solids hopefully will continue without competition.

Yearly expenses include \$2,995 per year for the electricity and \$3,360 to remove the solids from the shallow solid settling ponds. The pump was assigned a ten year life. The spreading cost of the manure was ignored as well as the offsite storage cost. The additional benefit of cleaning the barn is included in this system. The farmer, the veterinarian, and the hoof trimmer are pleased with the results of the flush system. These costs are shown in table 4.

**Table 4. Costs for wetland manure handling system for Farm B.**

|                           | Present Value | Yearly Amount |
|---------------------------|---------------|---------------|
| First Year Expense        | (\$94,920)    |               |
| Ten Year Expense          | (\$1,880)     |               |
| Operation and Maintenance | (\$62,396)    | (\$6,355)     |
| Nutrient Value Remaining  | \$32,930      | \$3,354       |
| Solids Sold               | \$58,910      | \$6,000       |
| Net Income                | (\$66,346)    |               |
| Net Income per Cow        | (\$390)       | (\$20)        |

Without including the nutrient value the system has a negative present value of (\$584) per cow over the 20 year life of the system. Some farms may not be able to obtain a benefit from the manure. Farms with fields that have high to excessive levels of phosphorus and potassium may even see these nutrients as a detriment. The lower amounts of these nutrients in the effluent of this system will make this less likely. Still appropriate nutrient management will be needed to utilize the nutrients properly. The variation of the nutrient concentrations because of the effects of weather on the process may make this system a little more difficult to develop a nutrient management plan. The ability to irrigate the effluent on growing crops without excessive odors will increase the likelihood that the nutrients can be used.

## Discussion

Both systems have some expansion capabilities planned in them. Farm A sized their system for 1000 cows while Farm B sized their system for 300 cows. Using their systems to their full capacity would of course reduce the per cow costs.

A comparison on just the cost basis is not complete since the electric prices, the farm sizes, and management objectives at each farm are different. Still table 5 shows the present value of each system with and without the nutrient value of the effluent.

**Table 5. Present values of the manure handling systems with and without the value of the nutrients.**

|   | Farm A | Farm B  |
|---|--------|---------|
| Present Value per cow (without nutrients) | \$15   | (\$584) |
| Present Value per cow (with nutrients)    | \$698  | (\$390) |

The irrigation cost of the effluent was not included on both systems. The amount to be irrigated on a per cow basis will be similar for each farm. Irrigation of the effluent should be the cheaper than tank spreading for both farms. The irrigation on both farms should be relatively easy since they both have low total solids in the effluent. Farm B has very low solids content in the effluent so irrigation will be very efficient. Both systems have biologically treated the effluent so that palatability problems as the effluent is sprayed on growing forage crops should not be an issue. Pathogen and weed seed reductions have probably occurred in both systems. If spills occur, the reduced BOD in the effluent should help reduce the effect on the environment.

The pond system and recycling pump on Farm B were a relatively low capital cost. A flat site with low permeability soil could reduce the costs of installation even further. Steep sites that require an artificial liner would be much more expensive. Retrofitting a flushing system into a flat barn would also be more expensive. An existing 2% slope on the alleys would be ideal.

Farm A did a good job of finding an appropriately sized used engine generator at a very reasonable cost. There may be ways they could have used an earth reinforced plastic lined digester to reduce the initial cost. If they could find a use for more of the electricity to change the value of the excess produced from \$0.02 per kW sold to the utility to \$0.09 per kW of avoided cost on the farm, the digester system would have even more value. They are using some

of the waste heat to heat water in the milking center. Smaller farms have higher per cow costs for a digester system.

## **Conclusions**

Both the wetland treatment system and the anaerobic digester are feasible systems for dairy farms that will provide excellent odor control. The costs of these systems are comparable or less than other manure handling systems. The management required is well within the abilities of most dairy farms.

There are advantages and disadvantages to each system that may be more or less important to each farm. The wetland system works very well with a flushing system to clean the barns. Gently sloping topography and relatively impermeable soils will keep the initial costs low. Farms that don't need all the nutrients in the raw manure may benefit from the nutrient losses of this system. The anaerobic digester system would be best for a farm that had high electric costs and could use the nutrients for crop production.

Nutrient utilization and by-product sales are important in reducing the cost of a manure handling system. Marketing the separated solids and fully utilizing the nutrients in the manure can help pay for odor treatment systems.

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